View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Archivio istituzionale della ricerca - Università di Modena e Reggio Emilia

MODELLING AND COLLABORATION AS COGNITIVE TOOLS IN PHYSICS EDUCATION

Federico Corni[1], Enrico Giliberti[2], Marisa Michelini[3], Lorenzo Santi[3] & Alberto Stefanel[3].

[1]Physics Department, University of Modena and Reggio Emilia, Via G.Campi 213/A, I-4110 Modena, Italy
[2]Department of Social, Cognitive and Quantitative Sciences, University of Modena and Reggio Emilia, Via A. Allegri 9, I-42100 Reggio Emilia, Italy
[3]Physics Department, University of Udine, Via delle Scienze 208, I-33100 Udine, Italy
E-mail: federico.corni@unimore.it, enrico.giliberti@unimore.it, michelini@fisica.uniud.it, santi@fisica.uniud.it, stefanel@libero.it

1. INTRODUCTION

The *Green Paper on teacher education in Europe* (Buchberger, 2000) highlights the crucial role of designing learning situations in which students can find opportunities to develop structures of meaning, knowledge and activities for a didactical reconstruction of the disciplinary contents, integrated with pedagogical competencies, methodologies and teaching practices.

In the case of Sciences, and of Physics in particular, the methodological characteristics of the disciplines lead also the didactical methodologies. The epistemic role of models in physics (Hestenes, 1996) suggests that models can be included in teaching and learning methodologies and cannot be omitted in a cultural base in science education of teachers of all levels. Models being cognitive tools and not simple formal descriptions of phenomena, they cannot be transferred either as ready-to-use examples or taught as rules to apply. Teachers should be prepared to offer specific experiences of model building starting from experimental activities (Michelini, 2004).

A special effort should be made in the training of primary school teachers. They, in fact, suffer from weak scientific cultural backgrounds, and the integration of their disciplinary and pedagogical competences are often left to their professional experience in the field.

This integration can be achieved by presenting scientific experiments as opportunities for personal involvement, identifying the variables, the relations and the dynamical structures of phenomena.

Modelling, fundamental in the scientific field, is fundamental in the process of teacher development too, as an instrument to acquire epistemological knowledge and as a “language” to approach, analyze, describe ad interpret phenomena.

Previous research (Corni, 2006) showed that some elementary recurring basic model structures represent “syntactic elements” of a language oriented to modelling. As an example, in the evolution toward equilibrium of different systems it is possible to identify the flow of an extensive quantity which is conserved and whose flux intensity depends on the difference in the levels of a corresponding intensive quantity experiencing a resistance.

A formative pathway was designed, with specific activities and monitoring tools, based on modelling and collaborative work, addressed to students of Primary Education of the Universities of Modena and Reggio Emilia and of Udine (Italy). Students had to design and perform three different experiments and to build the corresponding models with the VnR software. The three experiments consisted of the evolution toward equilibrium in three different contexts: the level of water in two communicating vessels, the potential in two parallel capacitors and the temperature of water in two containers placed one inside the other.

In the research presented here, the key role of group investigation in a cooperative learning environment (Sharan, 1992) was implemented in a community of prospective primary teachers. Our proposal consisted in a research-based learning pathway based on modelling and starting from experiments. The research aims to investigate how the modelling activity integrated with individual and group experimental analysis of selected situations produces learning of basic physics concepts. Moreover we detail the role of the VnR modelling tool, chosen because of its specific qualitative approach, specially suitable for primary school teachers.

2. Research Questions

The questions that, in particular, guide this work are the following:

RQ1. Are cooperative work and discussion helpful in selecting the relevant variables of a phenomenon, in recognizing correlations between them, both on the descriptive and on the interpretative level?

RQ2. Is modelling activity, with VnR in particular, useful in helping students in selecting variables, in recognizing model structures corresponding to physical concepts, and in the use of the feedback?

RQ3. How do the different contexts (hydraulic, thermal, electric) influence the above questions? Are there any significant differences between contexts from a didactical point of view?

3. Sample Groups

The 76 students from 2 university sites were grouped in two sample sets:

- Sample-set 1 (SS1), consisting of 64 second year university students from the Science Teaching for Primary School Educators Degree in Modena-Reggio Emilia University. During the activities these students were grouped in 14 groups of 3-4 students each.
- Sample-set 2 (SS2), consisting of 10 third year university students from the same class in Udine University. During the activities these students were grouped in 5 groups of 2 students each.

The two sample groups were considered separately for most of the data analysis, due to their numeric difference as well as their training backgrounds.

4. METHODOLOGY

To build formal thinking and to create a competence in the use of formal representation and relationships we choose an integrated approach based on:

1. Identification of the relevant variables, both individually and in groups
2. Experimental activity with data collecting and representation, both traditional and with on-line sensors
3. Modelling activity, using the modelling software VnR (Variables and Relationships) characterised by a qualitative approach

Each group of students had to perform three different experiments, not necessarily in order. According to the chosen methodology, we made use of three Worksheets and VnR software. The three experiments were chosen in order to compare similar phenomena in three different contexts, see Table 1.

#	Experiment	Extensive quantity	Conjugated intensive quantity	Reservoir	Capacitance	Resistor	Resistance
i	**Communicating vessels**	Water volume	Water level	Cylinder	Cross-section of the cylinder	Pipe	Hydraulic resistance†
ii	**Parallel capacitors**	Charge	Potential	Capacitor	Capacitance	Resistor	Resistance
iii	**Baun-marie**	Heat	Temperature	Water mass	Thermal capacity	Container wall	Thermal insulation‡

Table 1: Similarities between the three experiments. †Comprising the effects of the pipe impedance and of the fluid viscosity. ‡Inverse of thermal conductivity.

5. ACTIVITY SEQUENCE

5.1 STEP 1: PLANNING THE EXPERIMENTAL ACTIVITY

In the first step students had to plan the experiments to study the evolution toward equilibrium in the three different contexts: hydraulic, electric and thermal.

Worksheet A, used in the first activity (first individually then in groups), contains:

- Task: study the evolution with time of the process specifying the different initial conditions and the adopted parameters
- Materials

- Measurement instruments
- Planning hints
    A) Initial analysis of the task
    B) Designing of one or more procedures
    C) Feasibility study with the available resources
    D) Expected results
    E) Job subdivision within group members
    F) Execution of the experiment
    G) Log Writing
    H) Data report
    I) Results discussion and conclusions

5.2 Step 2: performing the experimental activity

In the second step students in groups performed the experimental activity, collecting measurements of the relevant variables and writing the log of the experimental work. Worksheet B guided the students in these activities. It is not presented here as it is considered not useful for data analysis.

5.3 Step 3: modelling activity

In the third step students were asked to build the model of the phenomenon. We choose to make use of the modelling software VnR due to its qualitative approach, in which the design of models is performed using icons. Column-like icons represent the variables and can be either positive-only or positive-and-negative. The links between variables represent relations, and can be either a static relation (sum, product, and their inverses) or dynamic (rate of change). Figure 1 reports some basic structures with the corresponding mathematical relations.

Students followed the Worksheet C, containing some questions useful to build the model: A) Which are the relevant quantities?; B) What are their relations?; C) Are there other quantities that can be considered and how do they affect the previous ones?; D) How can you explain it with a drawing or with words? How can you represent it using graphs, icons, etc.?

In the final part of the Worksheet C, students had to list all the variables and to specify their relations in a table (Table 2).

At the end of the Worksheet C, students had to draw on paper the expected model, before building it with the VnR software.

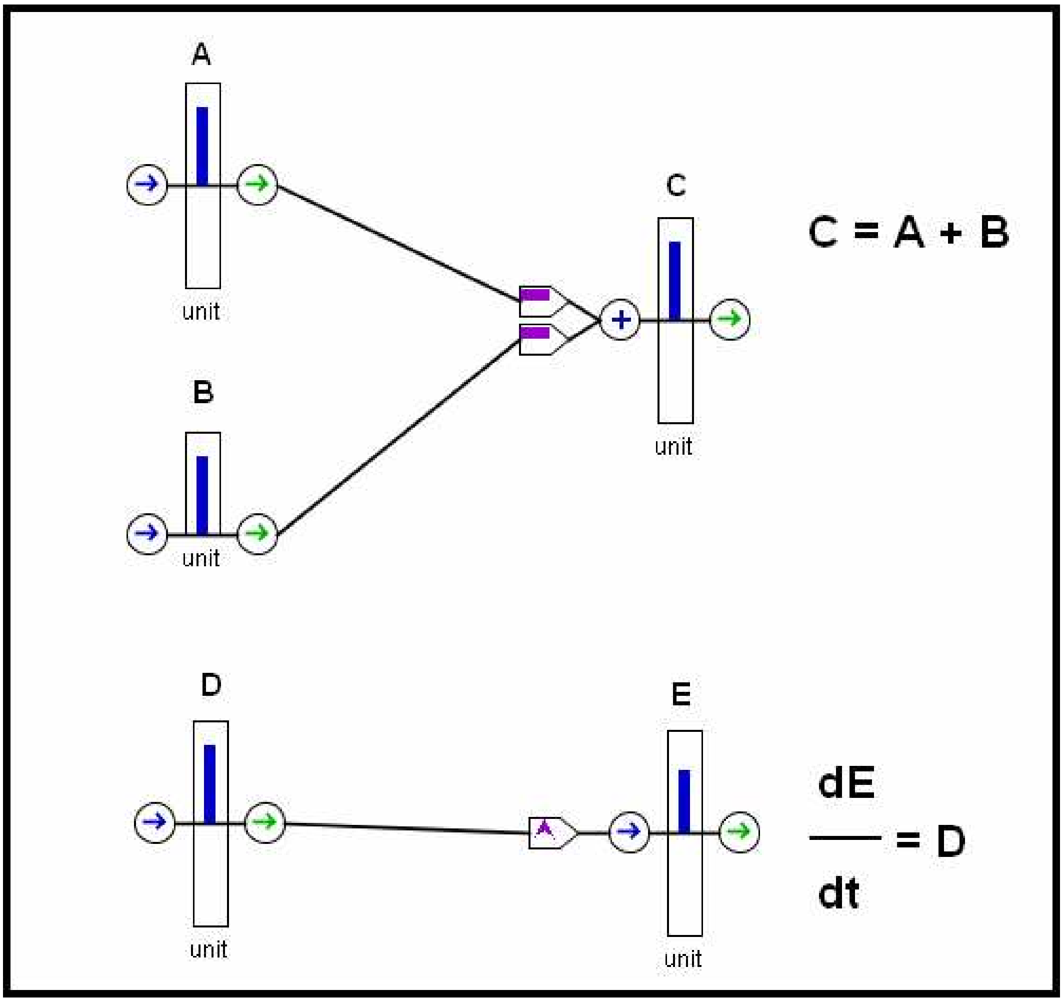

Figure 1: Basic relations in VnR.

6. Basic Concepts and Modelling

While filling Worksheet C students were expected to be able to find all the relevant variables and to include in the model the following basic concepts:

- Capacitance
- Difference of potential
- Resistance

Figure 2 shows a possible representation with VnR of the model of the three phenomena. The model is the same for the three processes, according to the parallelism among the basic concepts.

In the final discussion teacher pointed out the main similarities and difference among the experiments and the models built by the students.

Description of the physical quantity	Corresponding variable symbol	Is it a free quantity or is it dependant on other physical quantities?			
		Free		Dependant	
		It varies during the experiment (variable)	It is fixed at the beginning of the experiment, then it does not change (parameter)	Variables on which it depends (list the symbols)	Relation with the listed variables (use the symbol)

Table 2: Worksheet C, table for definition of the variables.

7. DATA ANALYSIS

Data related with the formative activity come from various sources, in particular from the recording of the group discussions, from the log of the experimental work and from the written answers to the worksheets used to guide the students during the experimental and modelling activities.

In order to investigate the role of the modelling activity we analyse and compare the group answers to Worksheets A and C and the group models made with VnR.

7.1 DATA FROM WORKSHEETS

The analysis of the role of the teamwork in the identification of the relevant quantities we compare the individual Worksheets A with the corresponding group ones.

Table 3 reports the physical quantities evidenced or mentioned by students in Worksheet A, according to the following criteria: A) Overall number of quantities; B) initial and final states of the phenomena; C) descriptive or kinematical variables, reporting the “movement” or evolution in time; D) interpretative variables (charge and current, energy and heat, mass and flow); E) process quantities (resistance, capacitance, conductibility).

Data are separated according to Sample-set (Modena and Reggio Emilia, and Udine), Individual and group data, Experiment (Communicating vessels, Thermal interaction, and Parallel capacitors).

The average number of quantities for each worksheet is 2.5. Group SS1 shows very little variation between individuals and groups. Group SS2 shows a larger variation, both increasing (especially in the case of Communicating vessels and of Parallel capacitors) and decreasing the

Number of Physical Quantities													
			Number of quantities		Initial/final values		Kinematic Variables		Interpretative Variables		Process Quantities	
Communicating vessels	N1	N2	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>
Individual	26	5	2,5	1,2	2,0	1,1	0,3	5,4	0,3	0,0	1,1	2,0
Groups	6	5	3,0	5,6	2,3	1,1	0,5	4,6	1,0	0,2	1,2	1,4
Thermal interaction between water masses	N1	N2	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>
Individual	22	4	2,4	7,8	1,3	1,3	1,0	0,8	0,3	0,3	0,9	0,0
Groups	8	5	1,9	4,0	1,4	1,3	0,6	0,6	0,3	0,0	0,8	1,2
Capacitors connected via a resistance	N1	N2	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>
Individual	2	10	3,0	2,7	1,0	0,0	1,0	0,0	0,0	0,9	1,5	0,7
Groups	3	4	2,7	5,8	1,3	0,0	1,0	0,5	0,0	0,8	1,0	1,5
Mean indiviual	50	19	2,5	3,4	1,6	0,6	0,6	1,6	0,3	0,5	1,0	0,9
Mean group	17	14	2,4	5,1	1,7	0,9	0,6	2,0	0,5	0,3	0,9	1,4

Table 3: Number of physical quantities, worksheet A.

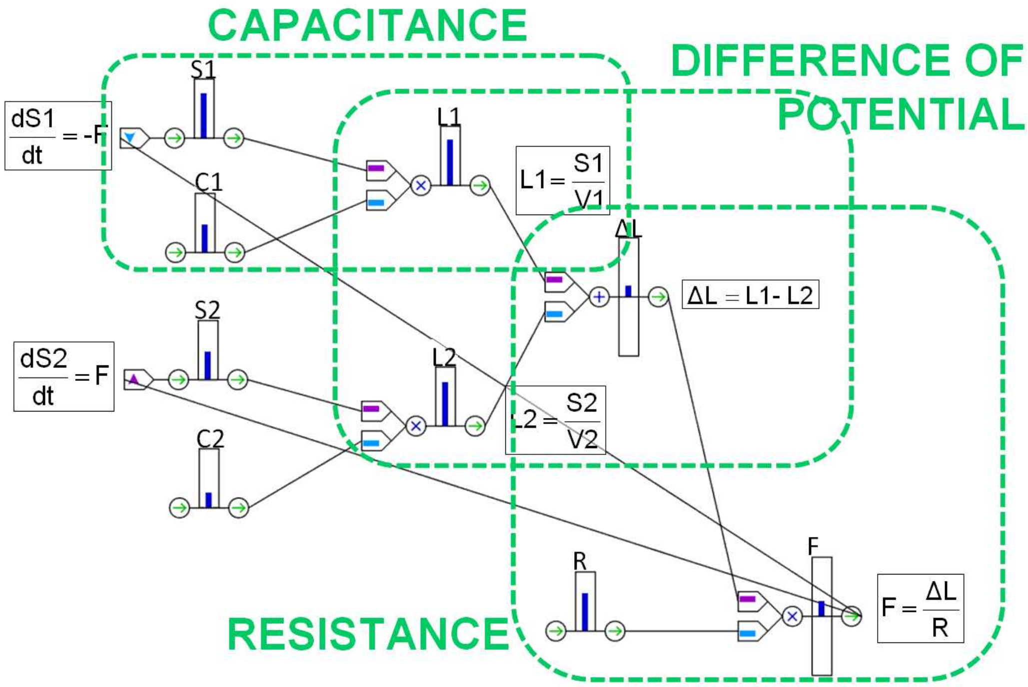

Figure 2: Possible model structure for the three experiments.

number of variables (Thermal interaction). SS2 shows a larger number of variables, both individual and group, in the case of Thermal interaction, probably due to a previous study of the thermal context.

SS1 reports a number of variables larger than SS2, both in initial and final states.

At least one descriptive or kinematical variable is reported; in the case of SS2 and Communicating vessels it is more marked, probably due to the presence of water, more evident to perception.

Interpretative variables (charge and current, energy and heat, mass and flow appear in a smaller number of cases compared with the descriptive ones ($< 30\%$).

At least one process quantity is reported, with few more variables considered by the groups of SS2.

Only small differences among contexts are recorded.

Table 4 shows the numbers and the percentages of individuals and groups mentioning the four relevant quantities (time, potential, difference of potential, current). The average of descriptive or kinematical variables (time, potential) increases after group activity. The peer cooperation facilitates the identification of the variables involved in the processes, helping groups to consider and combine the suggestions of the group members. This increase is not evident in the case of interpretative variables (difference of potential) and flow variables (current). This is probably due to the well-known difficulty of distinguishing between a variable and its variation.

Table 5 reports, for the three experiments, the comparison between the corresponding sections of Worksheets A and C, in particular counting the number of physical quantities reported.

			Time		Potential		Difference of potential		Current		Charge/ Heat/ Water volume		Capacity/ Thermal capacity		Resistance/ Thermal insulation/ Impedance	
	N1	N2	%n1	%n2	%n1	%n2	%n1	%n2	%n1	%n2	%n1	%n2	%n1	%n2	%n1	%n2
Mean individual	50	19	32	26	64	54	11	21	20	21	16	46	80	42	22	54
Mean group	17	14	41	71	65	81	14	16	18	37	12	74	76	68	18	39

Table 4: Percentage of relevant quantities, individual and group.

			Number of quantities		Initial/final values		Kinematic Variables		Interpretative Variables		Process Quantities	
Communicating vessels	N1	N2	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>
Worksheet A	6	5	3,0	5,6	2,3	1,1	0,5	4,6	1,0	0,2	1,2	1,4
Worksheet C	12	4	5,6	8,5	0,3	0,2	1,4	2,0	0,5	1,5	0,8	2,5
Thermal interaction between water masses	N1	N2	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>
Worksheet A	8	5	1,9	4,0	1,4	1,3	0,6	0,6	0,3	0,0	0,8	1,2
Worksheet C	12	4	6,0	5,4	0,6	0,5	1,8	2,0	0,7	0,2	0,9	2,6
Capacitors connected via a resistance	N1	N2	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>	<N1>	<N2>
Worksheet A	3	4	2,7	5,8	1,3	0,0	1,0	0,5	0,0	0,8	1,0	1,5
Worksheet C	10	3	5,9	7,3	0,4	0,5	1,8	1,8	0,6	1,5	1,2	2,8
Worksheet A	17	14	2,4	5,1	1,7	0,9	0,6	2,0	0,5	0,3	0,9	1,4
Worksheet C	34	11	5,8	7,0	0,4	0,4	1,7	1,9	0,6	1,0	1,0	2,6

Table 5: Number of physical quantities; comparison between worksheet A and worksheet C.

The comparison of the number of variables reported in Worksheet A with the number of variables reported in Worksheet C permits the observation that in each experiment the number of variables increases. The kinematical and the interpretative variables are reduced to the minimum, preserving only the variables necessary to have an adequate description of the phenomena. In the worksheet A students tend to consider all the variables suggested by the members of the group, but in worksheet C they are required to select only the relevant quantities, having to design the VnR model. Additionally a small growth in the number of process variables is noticed.

7.2 Data from VnR Models

Comparing VnR models and the corresponding models built on paper on worksheet C only few changes are noticeable. In particular the number of variables is systematically reduced, presumably due to the need to build a "working" model, performing a dynamical evolution, rather than achieving the right connections between the variables. Moreover, most of the models are referred to partial and specific aspects of the experiments, and the contribution of only some variables is considered. We classify the models according to the following categories: A) models with a linear structure connecting variables in the correct order but without feedback; B) models with feedback but without functional correlation; C) uncorrelated models; D) models in which a transfer of structure from models built previously is recognisable.

In Figure 3 some examples of each of the four categories are reported: A) Model with flux determined by the difference of potential; B) Model without feedback (uncorrelated); C) model with difference of potential, flux, feedback, resistance, capacity; D) Model with transfer. Models B), C) and D) were built by the same group of students and show the evolution in the ability of model building and the transfer of structure from one context to another.

Models distribution, classified according to the categories listed, are reported in figure 4. Category D, showing transfer between models, is well represented. Models of type A, with linear structure, showing no feedback, are essentially the first models built by each group, and the models of category D are the last, built during step 2 and 3 of the activities.

8. Discussion and Conclusions

From data reported in Table 1 it emerges that the role of collaborative group activity favors the recognition of the variables, enriching their number and focussing on the relevant quantities among the others. The peer collaboration contributed to the identification of descriptive model elements, but did not help significantly the interpretation of the observed phenomena (RQ1). On the other hand, the experimental activity, integrated with model design activity, enhanced the recognition and definition of variables as reported in Table 3, showing the comparison between worksheet A, related to the experimental activity, and worksheet C, related to the modelling activity. From Tables 1, 2 and 3 it emerges that students are inclined to build models making use of descriptive variables instead of interpretative ones (RQ2).

The VnR modelling tool can be considered a useful instrument to help the formalization of mathematical relations in students with poor mathematical background.

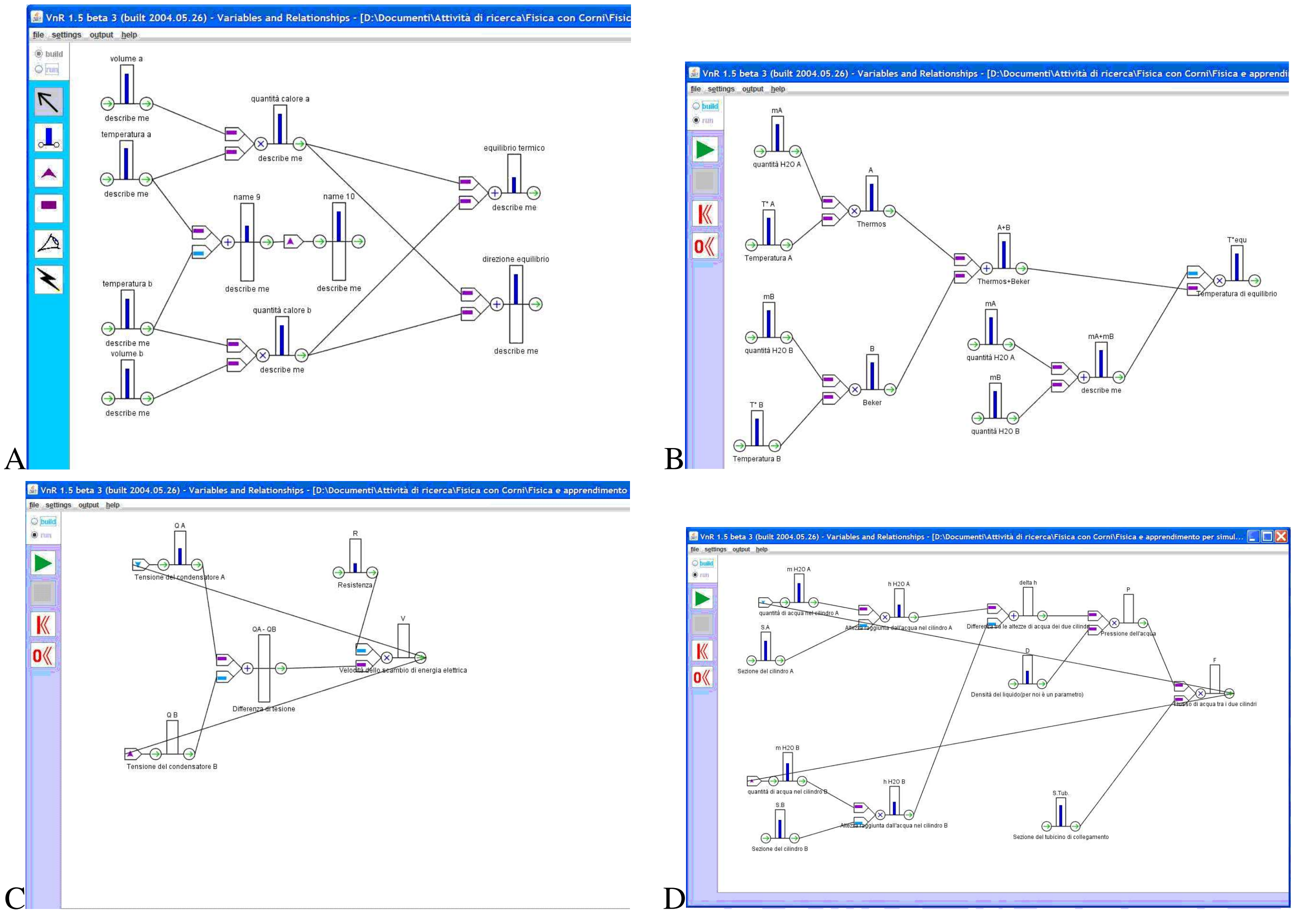

Table 6: Examples of VnR models built by students.

Specifically, the recognition of the role of flux and feedback, the construction of descriptive kinematical models and the recognition of model structures and their transfer from one context to another proved to have an important role in the construction of functional relations, as showed by the classification of models in figure 4. A lower effectiveness emerged concerning the transition from the descriptive plane to the interpretative one. VnR helped in the recognition of the relevant variables and of their basic connections. However such connections are more likely useful to ensure the functionality of the model, than connected to an effective organization of concepts (RQ2).

Concerning the role of different experimental contexts (hydraulic, thermal, and electric), it emerges, in particular, that their order of presentation is not relevant. Rather, the approach to different contexts having formally analogical models leads to the recognition of the various elementary component structures (RQ3).

REFERENCES

Buchberger, F., Campos, B.P., Kallos, D. & Stephenson, J. (eds), (2000), Green Paper on teacher education in Europe, *TNTEE, Umea, Sweden*.

Corni, F., Giliberti, E., Michelini, M. & Stefanel, A. (2006), The basic models in the experimental work

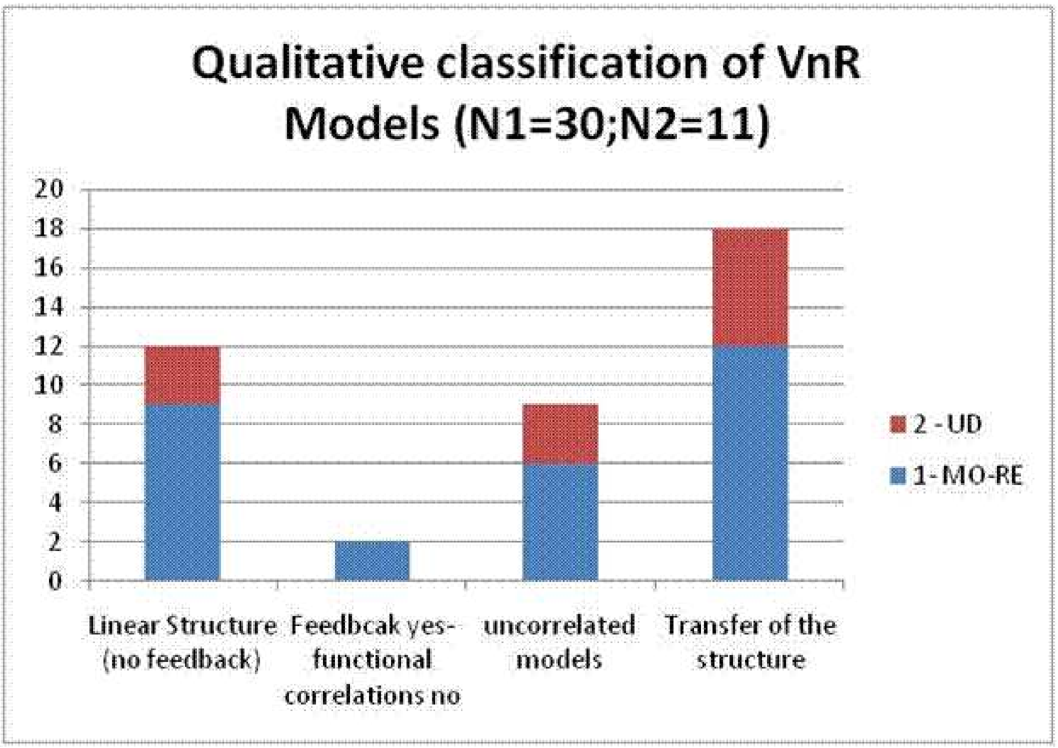

Figure 3: Distribution of the model categories.

of student-teachers of primary school *Modelling in Physics and Physics Education: Proc. of the GIREP Int. Conf.* (Amsterdam, The Netherlands, August 2006)

Hestenes, D. (1996), Modelling methodology for physics teachers, *Proc. of the Int. Conf. on Undergraduate Physics Education* (College Park, August 1996)

Michelini, M. (ed), (2004), Quality development of teacher education and training, *GIREP 2003 book of selected paper, Forum Edizioni*.

Sharan, Y., & Sharan, S. (1992), Expanding Cooperative Learning Through Group Investigation, *New York: Teachers College Press*.

INDEX